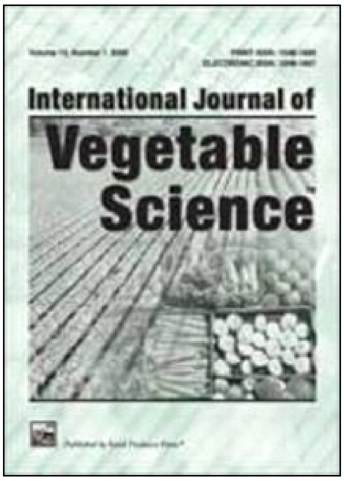

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Population of the Sweetpotato Whitefly in Response to Different Rates of Three Sulfur-Containing Fertilizers on Ten Vegetable Crops

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Whiteflies in the *Bemisia* complex are global pests on numerous horticultural crops. The effect of cultural practices on the population of the B-biotype sweetpotato whitefly, *Bemisia tabaci* (Gennadius), is only partly understood. A study was conducted to examine the effect of different rates of three common sulfur-containing fertilizers (ammonium sulfate, potassium sulfate, and superphosphate) on the population of *B. tabaci* in 10 vegetable crops. Three different rates were tested in the field for each fertilizer, but the specific rates were varied among crops to reflect the general use by growers in comparison with higher and lower rates. Egg, nymph, and adult whitefly counts were generally elevated with increased rates of ammonium sulfate or decreased with increasing rates of potassium sulfate. Conversely, field and laboratory data suggested a reduction in whitefly counts on cabbage and cucumber in response to increased rates of ammonium sulfate. However, whitefly populations within crops were generally the same regardless of rate of the superphosphate. Although each of the three fertilizers provides more than one essential nutrient, the individual role of sulfur, or any other nutrient, on the whitefly population was not identified. Nevertheless, the results from this study support that in certain sulfur-containing fertilizers, populations of the sweetpotato whitefly can be affected in several vegetable crops.

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Keywords *Bemisia tabaci*, B-biotype, Fertilizer rate, Plant nutrient, Pest management, Vegetable.

INTRODUCTION

Agricultural practices for vegetable production currently require high inputs of chemical insecticides and fertilizers. There are many well-documented safety, health, and environmental concerns, as well as the development of resistant insect pests, in association with high chemical usages. Whiteflies of the *Bemisia* complex, including the B-biotype of the sweetpotato whitefly, *B. tabaci* (Gennadius), have emerged as major crop pests on a global scale (Henneberry et al., 2002). B-biotype *B. tabaci*, which is synonymous with *B. argentifolii* Bellows and Perring, feeds on numerous species of crops (Cock, 1994; Greathead, 1986; Oliviera et al., 2001) and has been devastating to vegetable production. During the 1990s, the B-biotype sweetpotato whitefly spread across and damaged vegetables in key production regions of the United States (Henneberry et al., 2002) where it continues to be a problem. Similarly, whiteflies are often the most destructive insects of crops in Egypt (Abd-Rabou, 1998). Notably, during the past few years in Egypt, the B-biotype sweetpotato whitefly spread and attacked vegetable crops in most of the vegetable growing regions of the country. Despite increasing control efforts, plant injury and yield loss have also increased because of whitefly feeding. Changes in production practices, in particular the application of higher quantities of nitrogen and other nutrients and increased use of pesticides, may adversely affect the agroecosystem and promote elevated whitefly populations.

In Egypt, the B-biotype *B. tabaci* was found on 82 species of plants (Abd-Rabou, 1997). This whitefly has an expanding host adaptation and new host species have recently been identified in the United States (Simmons et al., 2000, 2008) and in other regions (Anderson et al., 2005). Cultural factors, such as soil fertility rate, can affect homopteran infestations (e.g., Cisneros and Godfrey, 2001; Godfrey et al., 2000; Jahn et al., 2005; Jauset et al., 1997; Simmons et al., 2000). There can be many differences in density of populations of whiteflies on taxonomically diverse vegetables and row crops (Numes et al., 2006; Simmons, 1994; Simmons et al., 2002). Moreover, the cultural practice for a given crop may be different. The research in this study focused on effects of some fertilizer cultural practices on the population of the B-biotype sweetpotato whitefly. Several types of sulfur-containing fertilizers are commonly used in alkaline soils. In key vegetable production areas of Egypt, the soils are characterized as alkaline. Many of those vegetables perform best in weakly acidic soils (Maynard and Hochmuth, 2007). The objective of this study was to determine effects of rates of common sulfur-containing fertilizers on the population of *B. tabaci* B-biotype in 10 vegetable crops.

MATERIALS AND METHODS

Field Experiment

Ten vegetable crops [broccoli, *Brassica oleracea* var. *botrytis* L., cv. Balady; cabbage, *B. oleracea* var. *capitata* L., cv. Soltani; cucumber, *Cucumis sativus* L., cv. Madina; eggplant, *Solanum melongena* L., cv. Aswad; green bean, *Phaseolus vulgaris* L., cv. Broncho; pepper, *Capsicum annuum* L., cv. Al-Hareef; potato, *S. tuberosum* L., cv. Clara; squash, *Cucurbita pepo* L., cv. Escandarany; tomato, *S. lycopersicum* L., cv. Castel Rock; and watermelon, *Citrullus lanatus* (Thunderg) Matsumura & Nakai ssp. *lanatus*, cv. Balady] were included in field tests in Egypt. Each crop was established in separate 0.5-ha field plots, and treatments were randomly assigned in each field. Broccoli, cabbage, cucumber, and squash were grown in Qalyubyia governorate; eggplant and pepper were grown in Minuofiya governorate; green bean was grown in Beni-Suef governorate; potato was grown in Gharbiya governorate; tomato was grown in Fayoum governorate; and watermelon was grown in Behira governorate. Squash and cucumber were the only crops grown in the same field, but they were planted in adjacent areas about 6 meters apart. The field study was conducted from July to Oct. 2005.

Soil varies among the different field locations used in this study. Soils in fields of the governorates of Gharbiya, Minuofiya, and Qalyubyia are characterized as clayey, pH of 7.6–8.2, 1.6–2.4% organic matter, 31–63 $mg{\cdot}kg^{-1}$ total soluble N, 3.3–14.0 $mg{\cdot}kg^{-1}$ available P, and 350–560 $mg{\cdot}kg^{-1}$ available K (unpublished data, Egyptian Ministry of Agriculture, 2006). Soils in Behira governorate are sandy, pH 7.4–7.6, 0.3–0.7 organic matter, 11–22 $mg{\cdot}kg^{-1}$ total soluble N, 2.2–5.1 $mg{\cdot}kg^{-1}$ available P, and 113–352 $mg{\cdot}kg^{-1}$ available K (unpublished data, Egyptian Ministry of Agriculture, 2006). Soils in Fayoum governorate are loamy, pH 7.5–8.0, 1.4–2.5 organic matter, 14–42 $mg{\cdot}kg^{-1}$ total soluble N, 2.3–15 $mg{\cdot}kg^{-1}$ available P, and 281–750 $mg{\cdot}kg^{-1}$ available K (unpublished data, Egyptian Ministry of Agriculture, 2006).

With the exception of eggplant and pepper crops, which received two fertilizer treatments, the crops received three fertilizer treatments, with three rates of each fertilizer tested (Table 1). The fertilizer sources and percentage of plant nutrients were ammonium sulfate, 20.5 (N) and 23 (S); superphosphate, 20 (P_2O_5) and 11 (S); and potassium sulfate, 50 (K_2O) and 17 (S). Only one fertilizer rate treatment was applied per plot. Rates were varied for a given crop according to the locally recommended mean fertility rate, and a lower and higher rate were in the test (Table 1).

Based on local production practices, nutrients were either added on a single date or on multiple dates for a given crop. For broccoli and cabbage, 50% of the ammonium sulfate was added 30 days after seeding and 50% was added 60 days after seeding; 100% of the potassium sulfate was added 30 days after seeding; and

Table 1: Total amount of each nutrient treatment added to separate plots of different vegetable crops in fields in Egypt 2005.

	Ammonium sulfate (kg·ha^{-1})			Potassium sulfate (kg·ha^{-1})			Superphosphate (kg·ha^{-1})		
Crop	**Rate 1**	**Rate 2**	**Rate 3**	**Rate 1**	**Rate 2**	**Rate 3**	**Rate 1**	**Rate 2**	**Rate 3**
Broccoli	238	476	714	71	95	119	179	238	298
Cabbage	238	476	714	36	60	83	179	238	298
Cucumber	571	714	857	143	214	286	214	357	500
Eggplant	714	952	1190	—[a]	—	—	357	417	476
Green bean	—	357	476	—	179	238	476	524	571
Pepper	476	714	952	—	—	—	452	476	500
Potato	714	893	1071	214	238	262	571	595	619
Squash	571	714	857	143	214	286	143	238	298
Tomato	1071	1310	1548	714	952	1190	357	595	833
Watermelon	571	714	857	143	214	286	214	357	500

[a]Dash indicates no data collected.

100% of the superphosphate was added 30 days after seeding. For cucumber, 33% of each fertilizer was added at planting, after 21 days, and at flowering, respectively. For eggplant, 50% of the ammonium sulfate was added 15 days after planting, and 50% was added at flowering; 100% of the superphosphate was added 15 days after planting. For green bean, 50% of the ammonium sulfate was applied 21 days after planting and 50% was applied at flowering; 100% of the potassium sulfate was added 21 days after planting; 100% of the superphosphate was added 21 days after planting. For potato, 80% of the ammonium sulfate was added 30 days after planting and the remaining was added 50 days after planting; 100% of the potassium sulfate was added 30 days after planting; 100% of the superphosphate was added 30 days after planting. For pepper, 50% of the ammonium sulfate was added 15 days after planting, 50% was added at flowering; and 100% of the superphosphate was added 15 days after planting. For squash, 33% of each fertilizer was added at planting, 21 days post-plant, and at fruiting, respectively. For tomato, 63% of each fertilizer was added 21 days after planting, 18% was applied 42 days after planting, and 18% was applied 63 days after planting. For watermelon, 33% of the ammonium sulfate was added at planting, after 21 days, and at flowering; 50% of the potassium sulfate was added at planting and 50% was added at flowering; 33% of the superphosphate was added at planting, after 21 days, and at flowering.

Forty days after planting, weekly samples of leaves (30) were collected at random from plants from within each plot after the number of adult *B. tabaci* were counted from leaves that were gently turned. A leaf sample was taken from the middle section of each randomly selected plant. Adult counts were made during early mornings (from about 08:00 to 09:00 a.m.) when whiteflies were not likely to fly when leaves were disturbed. Leaves were collected in paper bags, taken to the laboratory, and numbers of *B. tabaci* nymphs and eggs were counted with the aid of a dissecting microscope. Ten yellow sticky cards (10×25 cm) were placed per plot and were replaced during each sample interval. Samples were taken over 12 weeks. Correlation analyses (SAS Institute, 2002) were used to compare data between adult counts for the leaf sample method and the sticky card method. Student-Newman-Kuels test (SAS Institute, 2002) was used to compare means for whitefly counts across rates for the different fertilizers within crops. Significant differences were determined at $P < 0.05$.

Laboratory Experiment

Based on results from the field experiment, tests were conducted on cabbage, cv. Fortunn; cucumber, cv. Poinsett; green bean, cv. Ambra; and tomato, cv. Homestead, in the laboratory. These four crops represented contrasting responses of the whitefly among the crops tested in the field. In the laboratory, the plants were individually seeded in Jiffy Mix (composed of 1:1 Canadian sphagnum peat:vermiculite; pH 5.5–6.2; Jiffy Products of America, Batavia, Ill.) in 1.4×1.4 cm wide and 0.8 cm depth plastic trays in the greenhouse or in a growth chamber, where they were established. Two rates and a control of each of two fertilizers (ammonium sulfate and potassium sulfate) were used for each crop as follows: Rate 0 = water only, rate 2 = 0.5%, and rate 3 = 1.0% (w/v) for ammonium sulfate for all crops except rate 2 and rate 3 were 1% and 2%, respectively, for cucumber; rates of potassium sulfate were 0%, 0.5%, and 1% for all crops except rate 2 and rate 3, which were 1% and 2%, respectively for tomato. Each fertilizer type was dissolved in water and 25 mL was applied once per plant. The fertilizer treatments were applied to the plants during the first true leaf stage for cucumber, the unifoliate leaf stage for green bean, and the 3- to 4-leaf stage for cabbage and tomato. After 48 h following the addition of the fertilizers, all plants of one fertilizer were confined per cage. Three plants per fertilizer rate were arranged in a completely randomized design along a 33-cm-dia. circle within a Bug Dorm® (BioQuip Products, Rancho Dominguez, Calif.) insect cage. Then, 180 adult *B. tabaci* were released in the center of the cage. After 72 h, numbers of whitefly adults and eggs were counted on all leaves per plant. In addition, leaf area per plant was measured with a leaf area meter (model 3000; LI-COR, Lincoln, Neb.). The experiment was repeated seven to eight times for each crop. Means were separated by the Student-Newman-Kuels test (SAS Institute, 2002).

RESULTS AND DISCUSSION

Because field whitefly counts were highly correlated ($r = 0.99$, $P < 0.001$) between the two sampling methods (leaf and yellow sticky card) for the adult stage, only leaf sample data for the adults are presented. Adult leaf counts were highly correlated with leaf counts of eggs ($r = 0.83$, $P < 0.001$) and nymphs ($r = 0.97$, $P < 0.001$). Overall counts for each insect stage per crop were generally higher, or as high ($P = 0.05$), for plants receiving ammonium sulfate as compared with the superphosphate treatments, although all counts in cabbage were higher for the latter fertilizer (Figures 1–10). The overall whitefly counts per crop ranked second for the potassium sulfate treatments. In the field, increased rates of ammonium sulfate, and decreased rates of potassium sulfate, tended to have a positive effect on whitefly eggs, nymphs, and adults (Figures 1–10). The magnitude of the weekly population counts between the highest and lowest fertilizer rates was greater within some crops (broccoli, cabbage, cucumber, and tomato) than others (pepper and watermelon). Within cabbage and cucumber plots, the high and low rates of potassium sulfate varied by about twofold throughout the 12 weeks of sampling (Figures 2 and 3). Cabbage and cucumber consistently had reduced levels of whitefly eggs, nymphs, and adults with a reduction in ammonium sulfate rates (Figures 2 and 3). When compared to ammonium sulfate and potassium sulfate, there was generally no effect on whitefly populations due to different rates of superphosphate (Figures 1–10). An exception was tomato, in which there were consistently fewer numbers of eggs, nymphs, and adults, for the

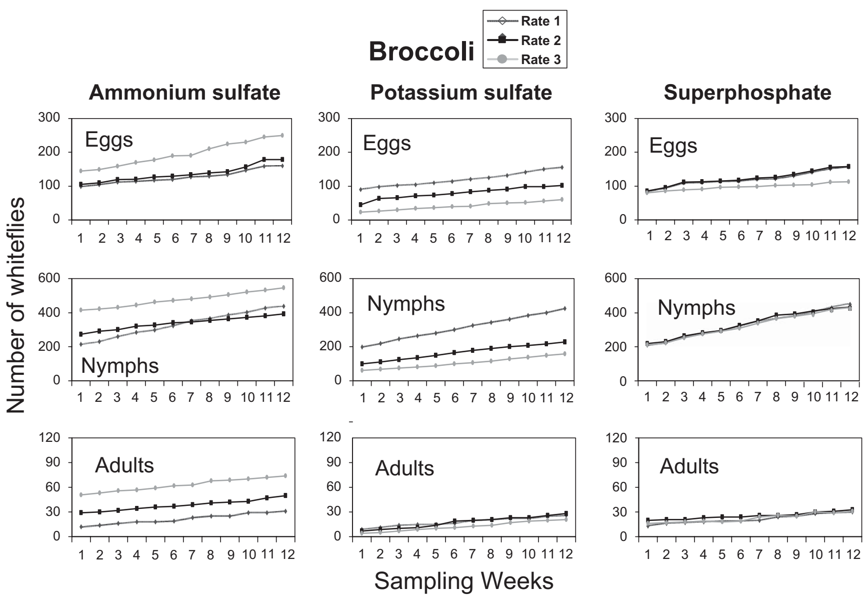

Figure 1: Mean numbers of whiteflies per 30-leaf sample of broccoli plants during 12 weeks following treatment with different rates (71–714 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

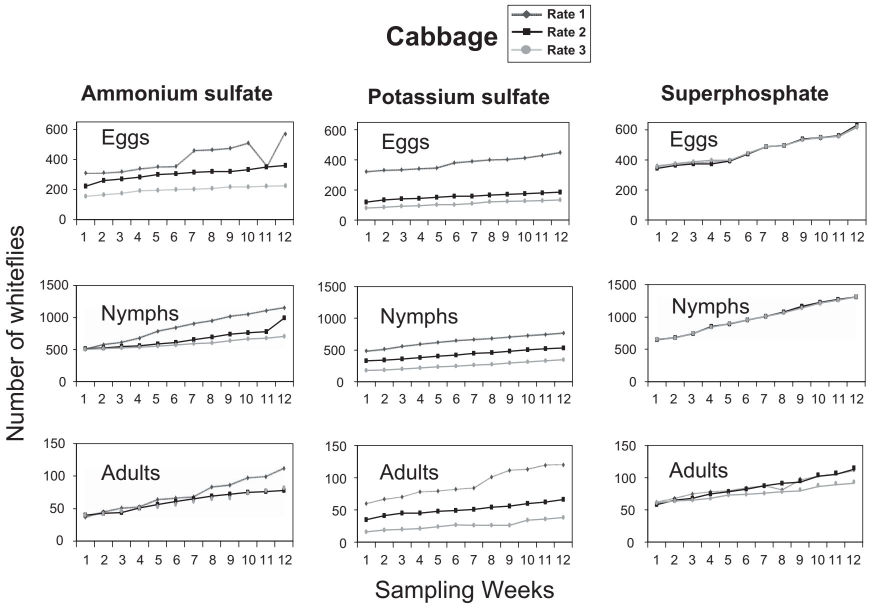

Figure 2: Mean numbers of whiteflies per 30-leaf sample of cabbage plants during 12 weeks following treatment with different rates (36–714 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

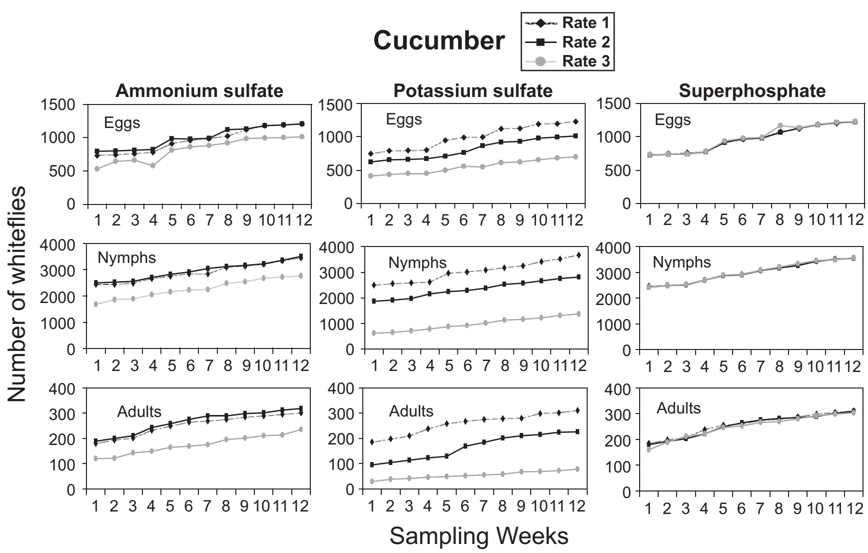

Figure 3: Mean numbers of whiteflies per 30-leaf sample of cucumber plants during 12 weeks following treatment with different rates (143–857 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

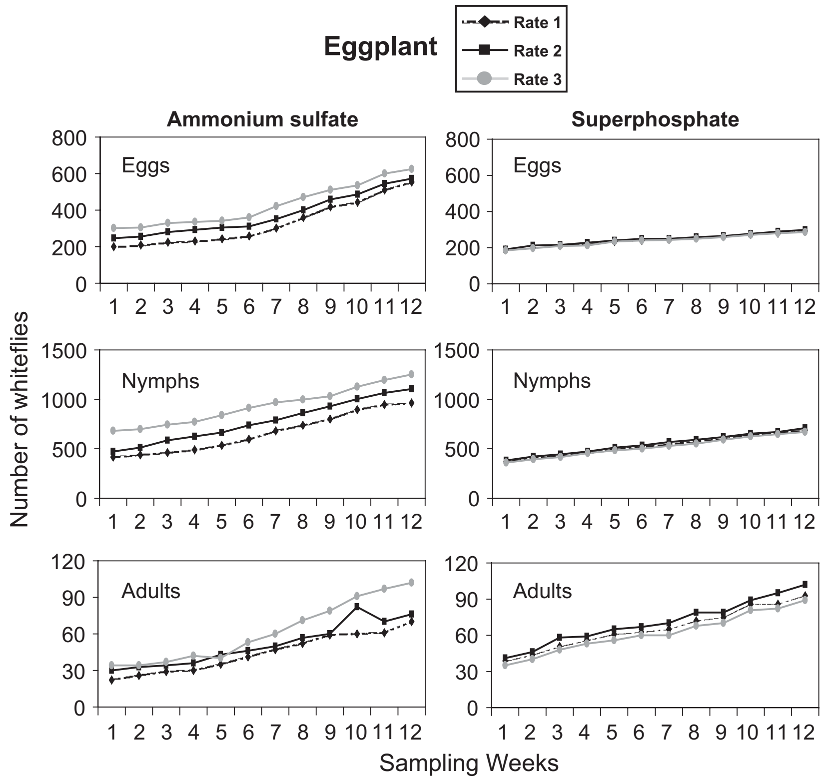

Figure 4: Mean numbers of whiteflies per 30-leaf sample of eggplant plants during 12 weeks following treatment with different rates (357–1190 kg ha^{-1}) of ammonium sulfate or superphosphate fertilizers in field plots.

highest rate as compared with the lower rates of superphosphate (Figure 9). Because of varying factors, including location and timing and amount of the fertilizer applications, comparisons of data among crops should be considered with caution.

Leaf area in the laboratory experiment was not correlated with counts of adults (r = 0.05) or eggs (r = 0.01). Count data were presented on a per plant basis. Apart from consistent trends in the laboratory, increased rates of ammonium sulfate or potassium sulfate generally did not have a statistically significant effect on whitefly adult or egg numbers within the four crops tested. The only significant effects were observed on cucumber and tomato. On cucumber, increased rates of ammonium sulfate resulted in significantly reduced numbers of whitefly adults (mean = 11.2, rate 0; 8.2, rate 2; 6.6, rate 3), which agreed with the trend for the eggs (mean = 105.5, rate 0; 64.5, rate 2; 74.4, rate 3), and with trends in the field (Figure 3). On tomato, increased rates of potassium sulfate resulted in significantly reduced numbers of whitefly

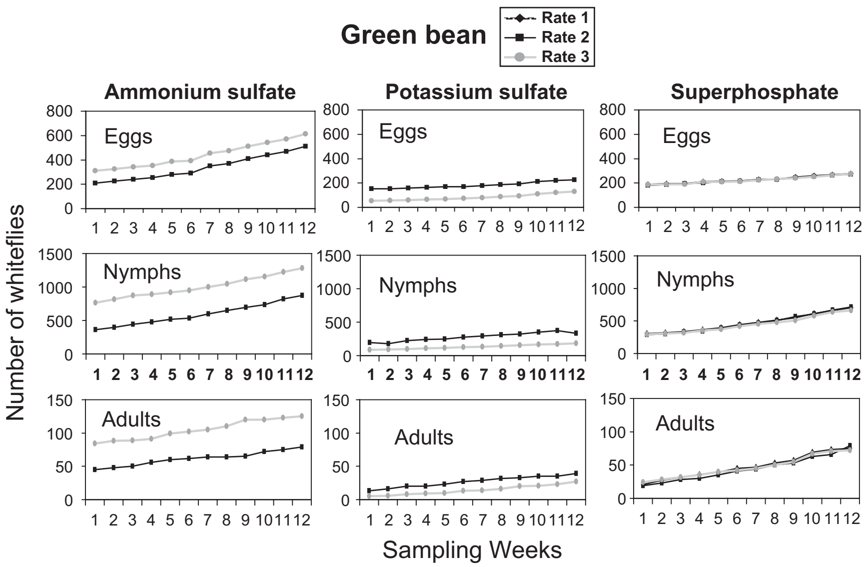

Figure 5: Mean numbers of whiteflies per 30-leaf sample of green bean plants during 12 weeks following treatment with different rates (179–571 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

eggs (mean = 34.1, rate 0; 27.4, rate 2; 18.5, rate 3), which was consistent with the trend for the adult counts (mean = 9.3, rate 0; 8.3, rate 2; 7.0, rate 3) and with trends for adult and egg counts in the field (Figure 9). On cabbage, non-statistical data trends for egg counts for ammonium sulfate (mean = 72.3, rate 0; 68.9, rate 2; 58.5, rate 3) and potassium sulfate (mean = 108.3, rate 0; 101.4, rate 2; 80.1, rate 3) followed trends observed in the field (Figure 2).

Plant nitrogen is probably the most documented plant nutrient affecting insect feeding response. Orozco-Cardenas and Ryan (1999) reported on the generation of hydrogen peroxide following the wound response in leaves of a wide diversity of plant species including several of the species in our test. It is not known whether such compounds could have interacted with whitefly feeding in our test. Whitefly populations were reported to be positively correlated with leaf nitrogen levels (van Lenteren and Noldus, 1990). Increased levels of nitrogen fertilizer were correlated with increased whitefly (*B. tabaci*) densities in one of five species of medicinal perennial crops (Simmons et al., 2000). In cotton, there was a higher population of this whitefly on plants fertilized with nitrogen as compared with plants deficient in nitrogen (Lin et al., 1999). Jauset et al. (1997) concluded that leaf site selections and incidence of the greenhouse whitefly [*Trialeurodes vaporariorum* (West.)] were positively related to increased nitrogen fertilizer and that leaf position is important to nitrogen content. The quantity and quality of plant nutrients and the composition of

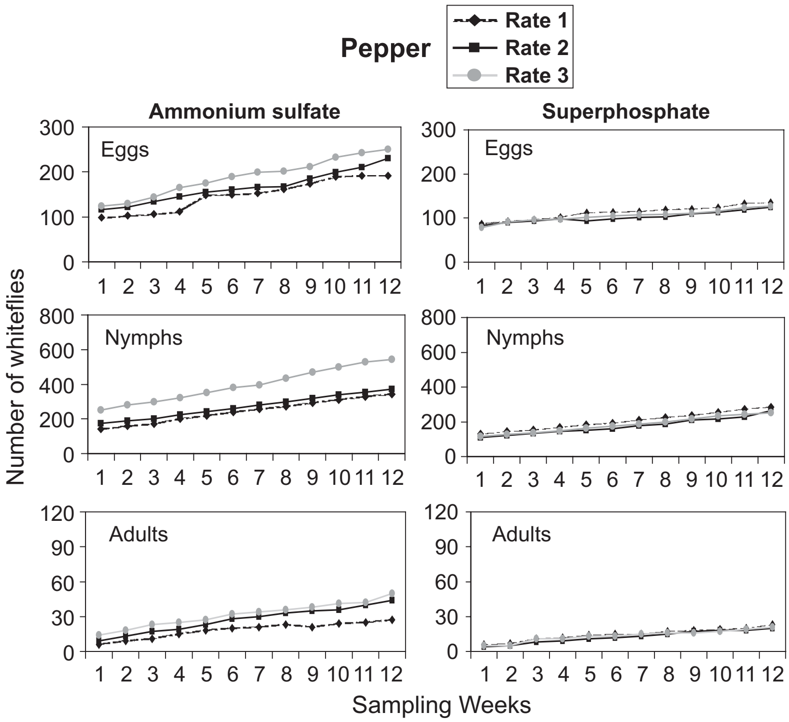

Figure 6: Mean numbers of whiteflies per 30-leaf sample of pepper plants during 12 weeks following treatment with different rates (452–952 kg ha^{-1}) of ammonium sulfate or superphosphate fertilizers in field plots.

nutrient combinations can be important in the ecology of insects. Blackmer and Byrne (1999) reported changes in whitefly populations following changes in plant amino acids. Ortega-Arenas et al. (2006) reported an increase in greenhouse whitefly egg and nymphal numbers on *Gerbera jamesonii* H. Bolus plants following an increase in plant nitrogen in greenhouse tests. Busch and Phelan (1999) concluded, based on modeling in soybean, that concentration and percentage of plant nutrients are important in arthropod populations. A normal sulfur rate on oilseed rape plants (*Brassica napus* L.) resulted in more than a threefold increase in oviposition by the cabbage root fly as compared with sulfur-free plants, but a rate twice the normal sulfur rate received the same number of eggs as the sulfur-free plants (Marazzi and Stadler, 2005).

The role of an individual nutrient was not the subject of this investigation. Each of the tested fertilizers supplied more than one essential plant nutrient, although sulfur is common for each. The specific effect from individual nutrients on whiteflies is not known in this study. The response of the sweetpotato whitefly to feeding on plants with the different rates of the different fertilizer treatments was generally consistent across crops, regardless of location. Moreover,

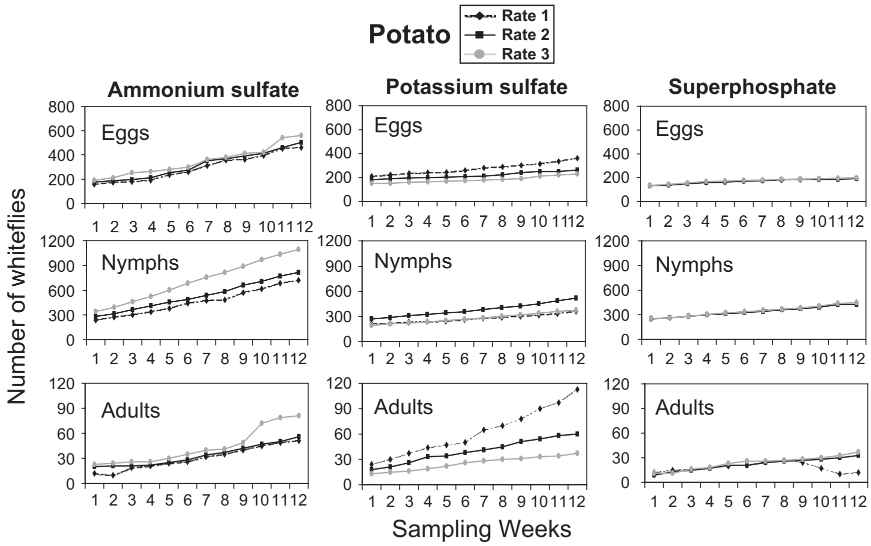

Figure 7: Mean numbers of whiteflies per 30-leaf sample of potato plants during 12 weeks following treatment with different rates (214–1071 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

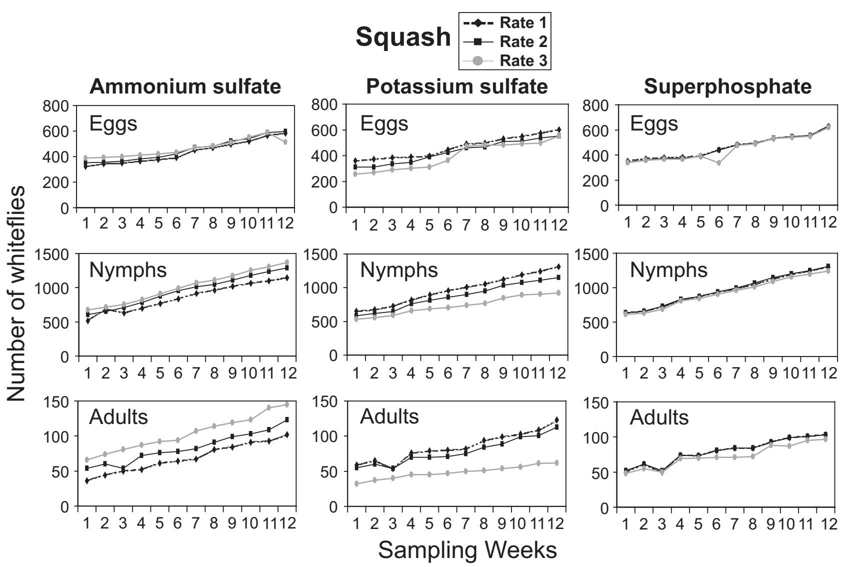

Figure 8: Mean numbers of whiteflies per 30-leaf sample of squash plants during 12 weeks following treatment with different rates (143–857 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

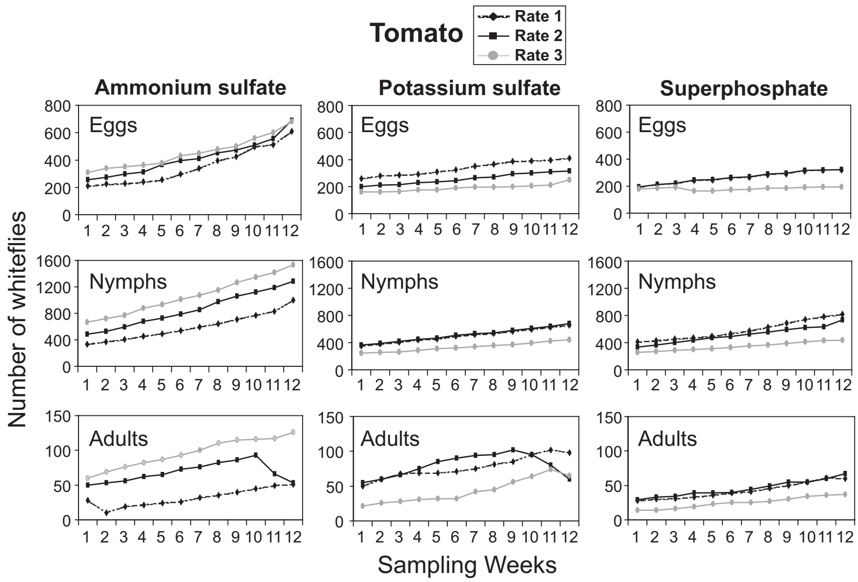

Figure 9: Mean numbers of whiteflies per 30-leaf sample of tomato plants during 12 weeks following treatment with different rates (357–1548 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

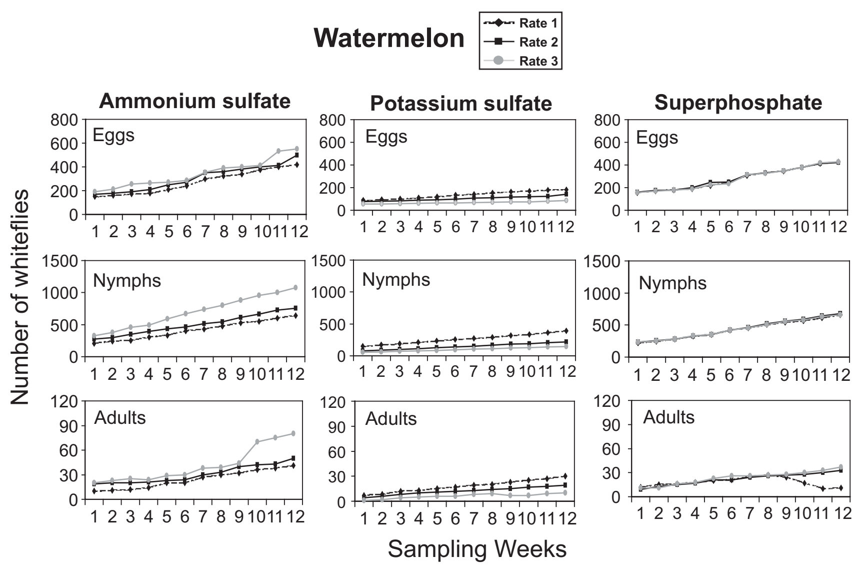

Figure 10: Mean numbers of whiteflies per 30-leaf sample of watermelon plants during 12 weeks following treatment with different rates (143–857 kg ha^{-1}) of ammonium sulfate, potassium sulfate, or superphosphate fertilizers in field plots.

the complementary data between the field and laboratory experiments support the conclusions about the fertilizers, although only four crops and two fertilizers were studied in the laboratory. This study demonstrates that use of these three fertilizers can have varying effects on populations of whiteflies in several vegetable crops. Depending on the particular fertilizer and its rate, there could be no effect (e.g., superphosphate), or the effect could be either negative (e.g., potassium sulfate) or positive (e.g., ammonium phosphate) in regard to populations of the sweetpotato whitefly.

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